Thermal Properties of Matter

Week 12, Lesson 1

- **Calorimetric examples**
- **Linear Expansion of Solids**
- **Area Expansion**
- **Volume Expansion**

References/Reading Preparation:
Schaum's Outline Ch. 15
Principles of Physics by Beuche – Ch.11.8

Summary of Calorimetry

Before we apply this idea to various examples, let us review what types of heat changes we may encounter:

1) When a mass m undergoes a temperature change from T_o to T_f, the amount of heat lost or gained is $Q = mc(T_f - T_o)$, where c is the specific heat capacity.

Remember that this only applies to temperature ranges which do not involve a change in phase of the material.

2) When a mass m melts, the heat exchange is $Q_f = +mH_f$;
when it crystallizes, $Q_f = -mH_f$

2) When a mass m vaporizes, the heat exchange is $Q_v = +mH_v$;
when it condenses, $Q_v = -mH_v$

Worked example

Determine the temperature t that results when 150 g of ice at 0°C is mixed with 300 g of water at 50°C.

Answer:

From energy conservation:

(heat change of ice) + (heat change of water) = 0

(heat to melt ice) + (heat to warm water) + (heat change of water) = 0

(ans. t = 6.7°C)

Worked example

How much heat is given up when 20 g of steam at 100°C is condensed and cooled to 20°C?

Solution:

Heat change = (condensation heat change) + (heat change of water during cooling)

(ans. –12,400 cal)

Thermal Expansion

As the temperature of a liquid or solid is raised, the molecules, having greater energy, generally vibrate through larger distances.

This increased amplitude of vibration of a given molecule forces its neighbouring molecules remain at a greater average distance from it.

Hence, the solid or liquid expands.

Generally, substances expand with increasing temperature - providing a phase change doesn’t occur.

The thermal expansion of the metal in a building or a bridge can be a matter of considerable practical importance.

If provision were not made for thermal expansion, railway tracks and concrete highways would buckle under the action of the hot summer sun (as has actually happened).

Therefore, it is necessary to know exactly how a material expands with temperature.

Linear expansion of solids

For many solids it has been found that over a certain range of temperature, the change in length of a material is linearly proportional to the temperature change.

We define the **coefficient of linear thermal expansion** α for the material by

$$\alpha = \frac{\text{Fractional change in length}}{\text{Temperature change}} = \frac{\Delta L/L}{\Delta T}$$

Which gives

$$\boxed{\Delta L = \alpha L_o \Delta T}$$

(the units are 1/°C or 1/K)

Area expansion

If an area A_o expands to $A_o + \Delta A$ when subjected to a temperature rise ΔT, then

$$\boxed{\Delta A = \gamma A_o \Delta T}$$

Where γ is the **coefficient of area expansion**.

For *isotropic solids* (those that expand the same way in all directions), $\gamma = 2\alpha$ (approximately)

Volume expansion

If an area V_o expands to $V_o + \Delta V$ when subjected to a temperature rise ΔT, then

$$\boxed{\Delta V = \beta V_o \Delta T}$$

Where β is the **coefficient of volume expansion**.

For *isotropic solids* (those that expand the same way in all directions), $\beta = 3\alpha$ (approximately)

Worked example

Suppose slabs of concrete 20 m long are laid end to end to form a roadway. How large a gap should be allowed between the slabs at -20°C so that they don't buckle at +50°C?

(ans. 1.4 cm)

Worked example

A copper bar is 80 cm long at 15°C. What is the increase in length when it is heated to 35°C? The linear expansion coefficient for copper is 1.7×10^{-5} °C^{-1}.

(ans. 2.7×10^{-4} m)

Worked example – volume expansion

Determine the change in volume of a block of cast iron 5 cm x 10 cm x 6 cm, when the temperature changes from 15°C to 47°C. The coefficient of linear expansion of cast iron is 0.000 010 $°C^{-1}$.

(ans. 0.29 cm^3)